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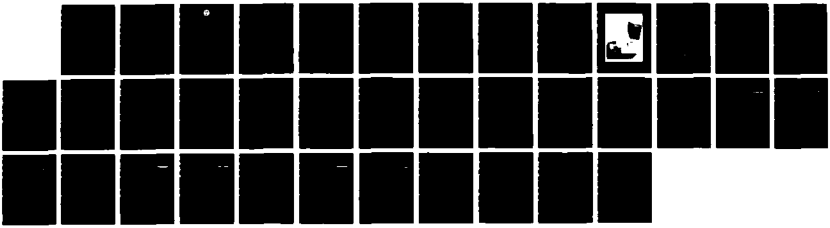

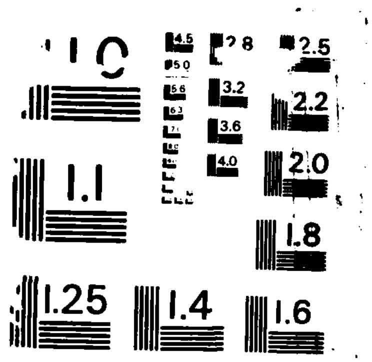
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TD 741

TD 741

Technical Document 741

30 September 1984

BUILDING 1 COOLING TOWER OZONE PROJECT

J. P. Hurley
Environmental Sciences Division

Naval Ocean Systems Center
San Diego, California 92152

NAVAL OCEAN SYSTEMS CENTER SAN DIEGO, CA 92152

AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

F. M. PESTORIUS, CAPT, USN
Commander

R.M. HILLYER
Technical Director

ADMINISTRATIVE INFORMATION

This task was sponsored by Civil Engineering Laboratory, Port Hueneme, CA under Project Ozone, Program Element 63725N. Work was performed during the period April 1983 and February 1984, and the document was approved for publication on 25 July 1984.

Released by
E. J. Wesley, Head
Radiation Physics Branch

Under authority of
R. R. Soule, Head
Environmental Sciences Division

RB

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

27 June 1988

NOSC Technical Document 741 (DTIC AD A148 902), "Building 1 Cooling Tower Ozone Project," by J. P. Hurley, 30 September 1984.

ADDENDUM

When using the information in NOSC TD 741, readers should note that the total volume of the cooling water system was 80,000 gallons.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A description is given of the use of ozone to treat circulation water in the NOSC Building 1 cooling tower. Topics include tower operating data, ozone equipment installation and operation, chemical and bacterial analyses, problems encountered, and benefits realized.

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INTRODUCTION

The total treatment of water circulated in cooling towers has always presented problems which were difficult to solve completely. Although the chemicals which have been used (usually chlorine or chlorine-based) have been relatively successful in controlling the growth of most bacteria, they have not been successful in eliminating scaling, fouling, and corrosion of tower and condenser tube surfaces. Furthermore, the heavy use of chemicals also presents serious difficulties in meeting current EPA and OSHA air and water quality standards. A need exists, therefore, for a new and effective method for the total treatment of cooling tower water. It is thought by many that ozone may be a good candidate for that application.

In an article written in 1970, Ogden (ref. 1) proposed the use of ozone as a replacement for chlorine in the treatment of fresh water in cooling towers. In a subsequent NASA program, Humphrey and French (ref. 2) addressed such subjects as: (1) ozone efficiency and lifetime in water, (2) methods of mixing ozone in the water, (3) required dosages, (4) chemical concentrations allowed, (5) sensitivity to corrosion, (6) equipment longevity and reliability, and (7) relative costs of using ozone. In their work, the authors were sufficiently impressed with the initial results that they limited the entire project to only ozone. In the same time period, the engineering firm of Brown and Caldwell (ref. 3) was retained by the Electric Power Research Institute (EPRI) to examine four cooling towers which were using ozone instead of chemicals to treat the water systems. The findings were similar to those of reference 2. A monograph published in 1981 by the International Ozone Association (IOA) (ref. 4) included a series of articles describing histories associated with the use of ozone in various cooling tower water systems. In all cases, the results were described as satisfactory, with substantial benefits claimed for the ozone.

The present work was undertaken as a combination test and demonstration project, where selected measurements would be repeated to establish guidelines for the proper use of ozone in Navy cooling tower water systems.

The following text will describe the NOSC experiment, including cooling tower operating parameters, ozone equipment installation and operation, chemical and bacterial analyses and their results, problems encountered, benefits realized, and recommendations for future Navy ozone applications.

EQUIPMENT AND INSTALLATION

For the present experiment, the ozone production system comprised an oxygen concentrator and an ozone generator. Both units were provided at no cost to the Navy for the measurements by ARCO Environmental, a subsidiary of the Atlantic Richfield Company.*+ In the generator, an ARCO Model 12T, the ozone is produced in the conventional manner (ref. 4) by passing air through a corona (glow) discharge created by high voltage (typically 10 kV) oscillating at 60 Hz. The electrode structure is cylindrical, with the discharge confined to the narrow gap between the concentric electrodes. To prevent arcing and maintain a stable discharge, a third cylinder of dielectric material, ceramic or glass, is inserted in the space between the electrodes. In the model 12T generator, the cylinders are assembled in two groups of six, with the tubes in each group connected in parallel and the two groups connected for series flow.

The oxygen concentrator is an auxiliary unit which conditions the air for ozone production by increasing oxygen concentration and reducing moisture content (ref. 4). Air entering the concentrator is directed through an adsorption column to remove nearly all the water vapor and approximately 90 percent of the nitrogen. The result is a clean, dry, feed-gas with an oxygen concentration of approximately 88 percent (as compared to the typical 20 percent O_2 in air). The concentrator used in the present measurements comprises three selectively doped molecular sieve adsorption columns and a small compressor. The unit uses a reverse flow pressure swing cycle for regeneration, with the pressure differential provided by the compressor, and desorption occurring at atmospheric pressure. The columns are time cycled at 1-second intervals so that one will be adsorbing while the other two are charging and desorbing. The concentrator/generator assembly is shown in the diagram of figure 1 and in the photograph of figure 2.

The oxygen concentrator and Model 12T ozone generator system were calibrated by the standard iodometric titration system (ref. 5). At a gas flow of 10 SCFH, the calibration showed the ozone production rate to be 0.32 pounds/day, or 5.7 grams/hour on a 24-hour basis.

Two different techniques were used to inject ozone into the cooling tower water. The first, and the simpler of the two, consisted of submerging two air dispersion stones in the tower basin, as shown in the diagram of figure 3. The stones were positioned directly over a return (down flow) line to ensure that the water flow would entrap and carry all the gas down to the water system below and none would escape. With the stones in that position, no surface bubbling was observed, indicating that little, if any, gas was lost at the contact point. The initial gas flow conditions were 8-9 SCFH for the flow and 0 PSIG for the back pressure. However, when after two days of operation the gas flow began to decrease and the back pressure began a corresponding increase, the stones were examined for fouling. Both were badly clogged with particulate matter (e.g., algae) from the basin water. Cleaning the stones restored

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* During the course of these measurements, ARCO Environmental sold the rights to their ozone technology to Sandhill, of Pasadena, CA.

\+ The description of the commercial equipment used in the present work does not constitute an endorsement by the Government.

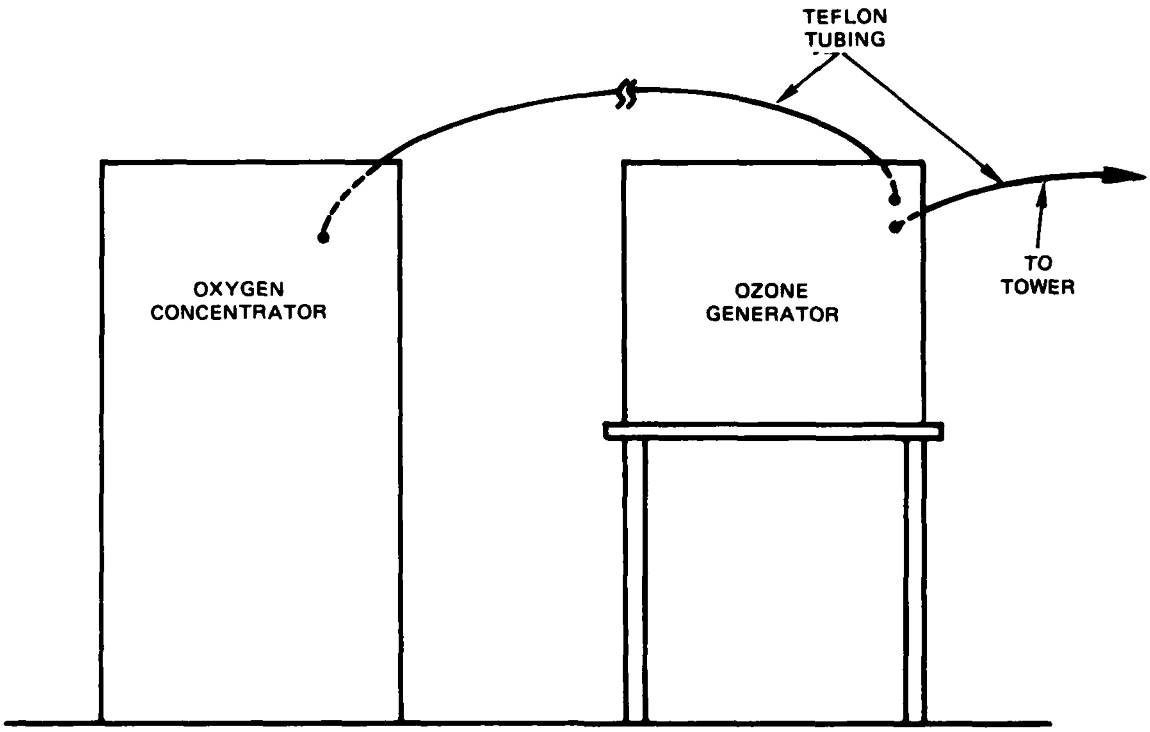

Figure 1. Diagram of the oxygen concentrator/ozone generator assembly; components are shown approximately to scale.

the system to the initial conditions for one day only, indicating that fouling would be a chronic problem and that it was necessary to change the injection method. The next technique adopted, and one that proved to be successful, used a circulation pump and an injection nozzle in a parallel loop, as shown in the diagram of figure 4. The suction line was submerged at one end of the basin and the discharge line was submerged at the other, to ensure good separation. As in the case of the stones, the discharge line was positioned over the return (down flow) line to avoid gas escape. No bubbling was observed when the line was submerged in this manner. Because the injector nozzle created a negative pressure on the gas line, the gage was "pinned" as a low limit and the flow was 10 SCFH. The circulating pump was driven by a 0.75-hp motor to produce a water flow of 20 gallons/minute and ensure a low injector nozzle pressure for good ozone mixing. Because many materials are sensitive to the oxidizing power of ozone, teflon tubing and stainless steel fittings were used on all ozone gas lines. In the water circulating loop, tygon was used for the ozonized water line, with the injector installed on the discharge (downstream) side of the pump to protect it against high ozone concentrations. The circulating loop system worked satisfactorily during the course of the experiment.

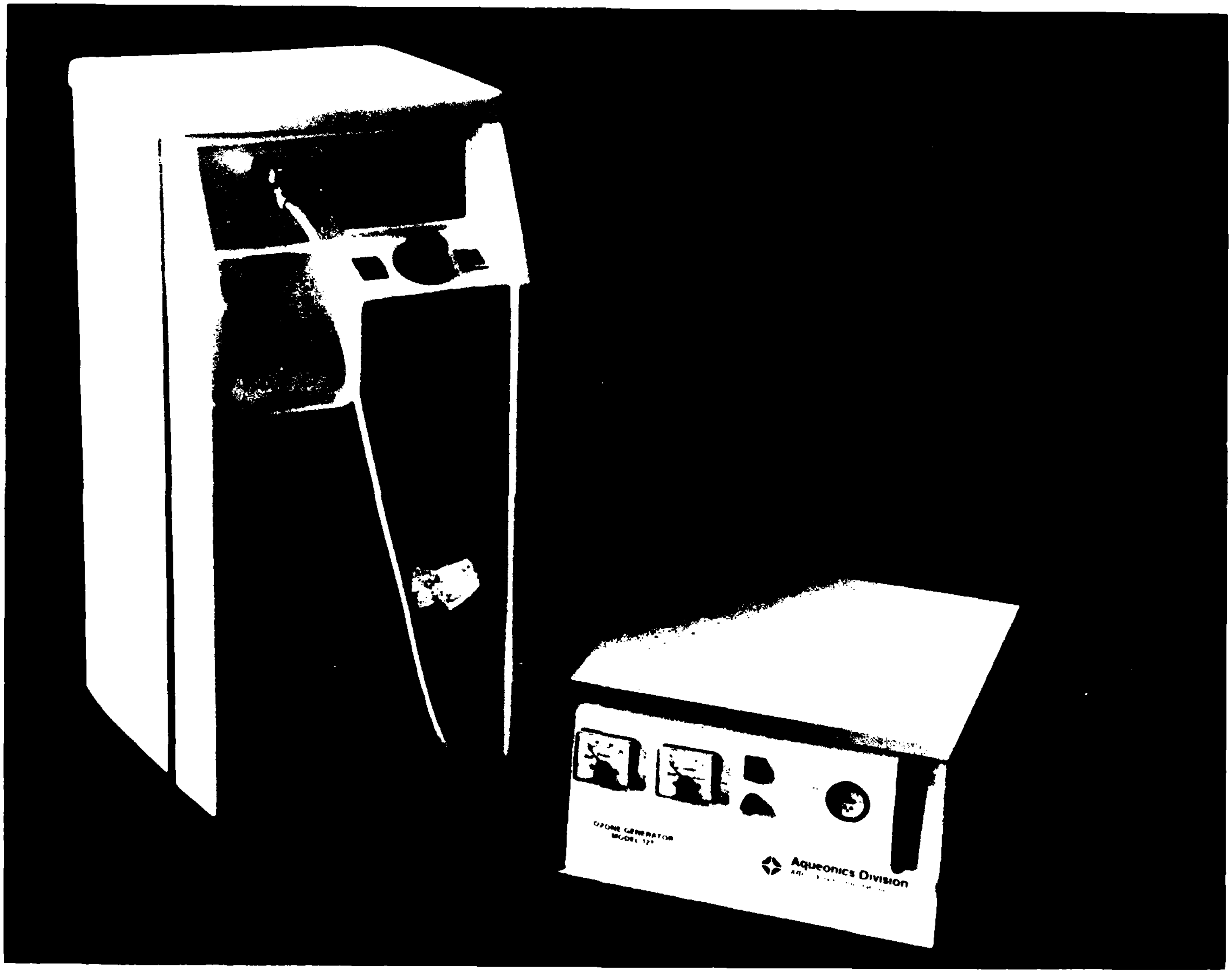

Figure 2. Photograph of the oxygen concentrator, ozone generator, circulation pump, and ozone injector.

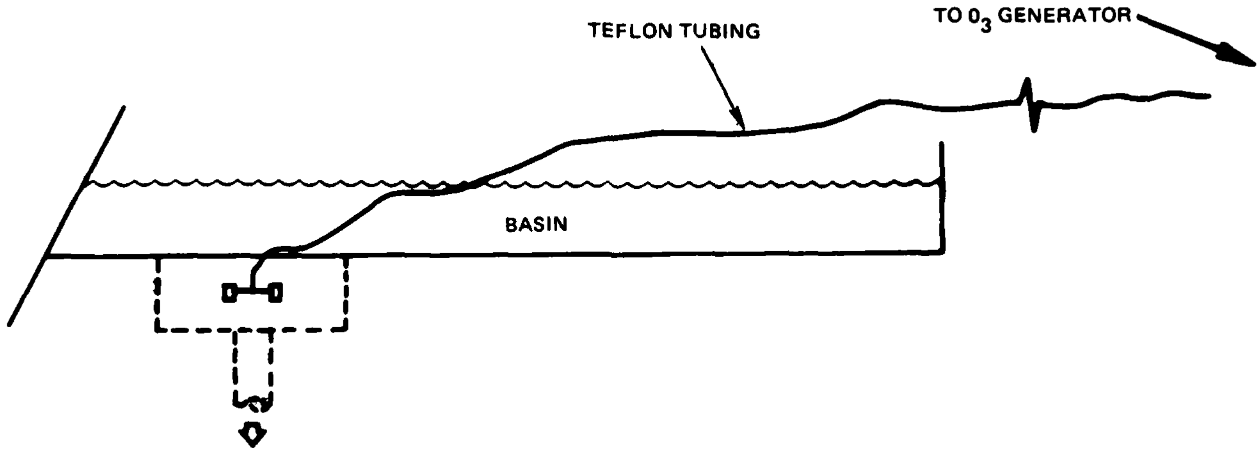

Figure 3. Diagram of the air stones ozone injector system. This method was abandoned early in the experiment when the stones became badly fouled.

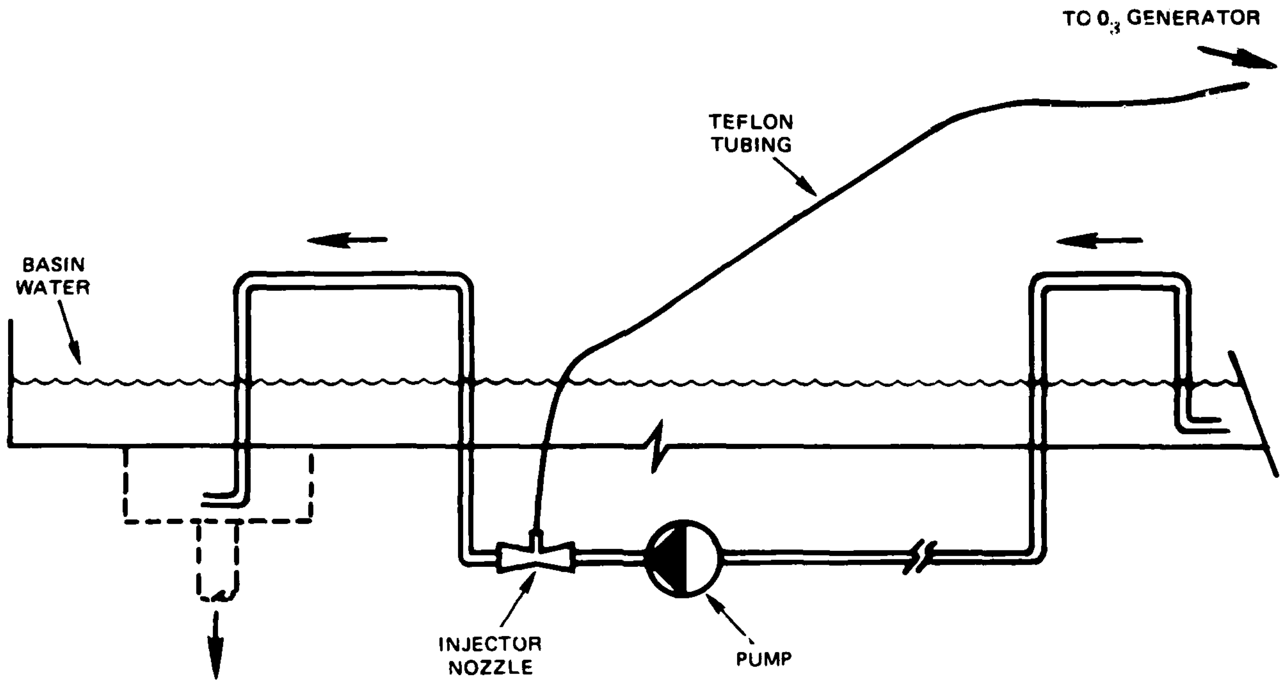

Figure 4. Diagram of the parallel circulation loop for the injection of ozone.

MEASUREMENTS AND RESULTS

On 7 June 1983, the ozone system was installed on the NOSC Building 1 cooling tower. During the initial phase of the experiment, only the oxygen concentrator was energized to produce a gas flow, without ozone, while the tower remained under standard chemical treatment. The gas system was monitored for performance, including variations in flow and backpressure, and for evidence of bubbling at the contactor submergence point. It was at this time that the air stones were replaced with the circulation loop after fouling was observed. Also, to establish a pre-ozone baseline for subsequent comparison, a series of water system measurements was made. These included chemical and bacterial levels, total (make-up) water and bleed-off* water volumes, and total dissolved solids (TDS) level. Under chemical treatment, the TDS level was (and still is) maintained at an adjustable, selected level of 1800/mg/l using an automatic bleed-off control. To maintain the 1800 mg/l value, the required bleed-off averaged only 126 gallons per day, a surprisingly small amount. The total (make-up) water consumption, on the other hand, averaged nearly 10,000 gallons per day, a startling result. The water meters, which were installed expressly for this project, were carefully calibrated to verify the results.

On 26 July 1983, after the ozone system operation was well stabilized and an adequate baseline had been established, all chemical treatment was suspended, the bleed-off was stopped, and the ozone generator was energized. The chemical and bacterial analyses begun earlier were continued, with the samples sent to an outside laboratory (ref. 6) on a weekly basis. Daily examinations of the tower and the water system continued, with visual inspections made of the tower surfaces (e.g., scale) and the water itself (e.g., color, clarity). Performance of the thermal transfer units in the mechanical system was monitored by recording input/output temperature differences. The mechanical/water system is shown in simplified form in the diagram of figure 5. In that system, the cooling tower water removes heat from two chillers which provide cooling for the building computer space, while also cooling two compressors which maintain air pressure for the building pneumatic control system.

The ozone treatment continued without bleed-off until 3 September 1983, when a decrease in the chiller temperature differentials (ΔT's) indicated reduction in their thermal transfer efficiency. An examination of the condensers revealed scale formation on the walls of the tubes. The scale material, later shown by chemistry to be silicon, was so firmly deposited on the tube surfaces that acid washing was required for complete removal. Reference to the chemical analyses (see appendix A) showed that in the absence of any bleed-off, the TDS level had climbed to 9300 mg/l (see figure 6), representing approximately 23 cycles of concentration versus the 4 cycles represented by the

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* While the term make-up is self explanatory, the expression bleed-off (also called blow-down) should be defined here. Under evaporation, chemicals dissolved in the tower water are left behind, raising their concentrations. The residual concentrations will continue to increase unless controlled. One such control is bleed-off, where a portion of the high-chemical-composition water is discharged to the drain system and replaced by service water with a low chemical composition.

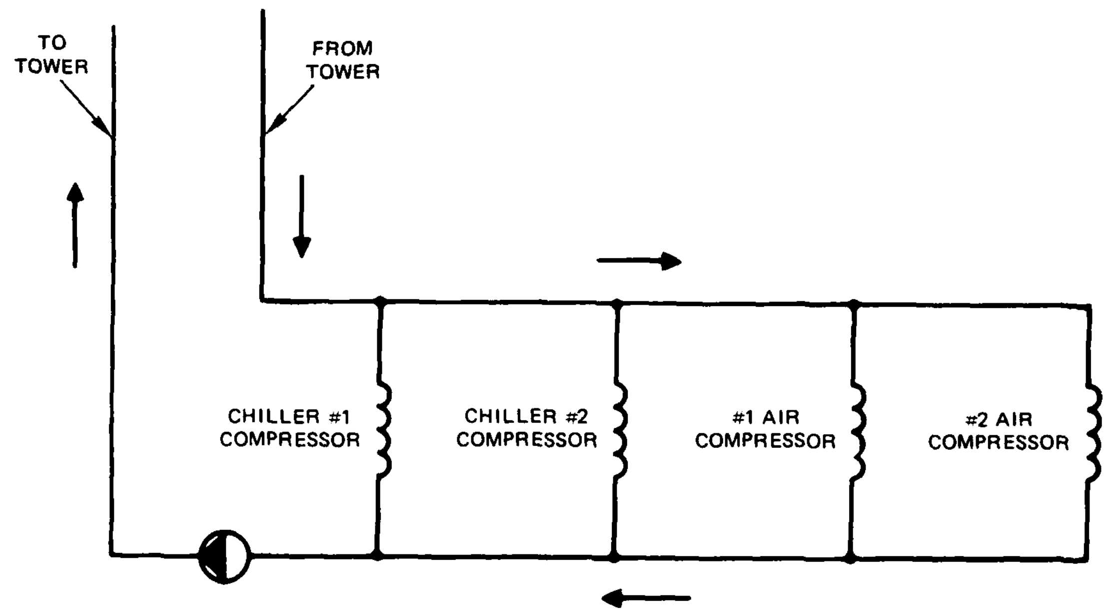

Figure 5. Simplified schematic of the NOSC Building 1 chiller condenser and air compressor cooling water loop.

controlled TDS level of 1800. The analyses also showed that the silicon (as SiO_2) level had climbed to 90 mg/l (see figure 7), well above its ambient temperature saturation concentration of 70 mg/l. These data readily explain the scaling encountered in the chiller condensers. To control the silicon level, the bleed-off was adjusted so that about twice the TDS baseline value of 1800 mg/l was maintained. Note the drop in both TDS and silicon levels following the bleed-off adjustment, as shown in figures 6 and 7.

On 28 October, the ozone treatment was terminated when one of two aluminum side plates on the water jacket of one air compressor ruptured. Inspection revealed that corrosion had been occurring at the rupture point, and the ozone, on line at the time, was held responsible. This topic is discussed further in the next section.

To establish a post-ozone chemical/bacterial data baseline, a series of 10 water samples was submitted to a Navy chemical laboratory (ref. 7), with the analyses made on a weekly basis from 12 December 1983 to 13 February 1984.

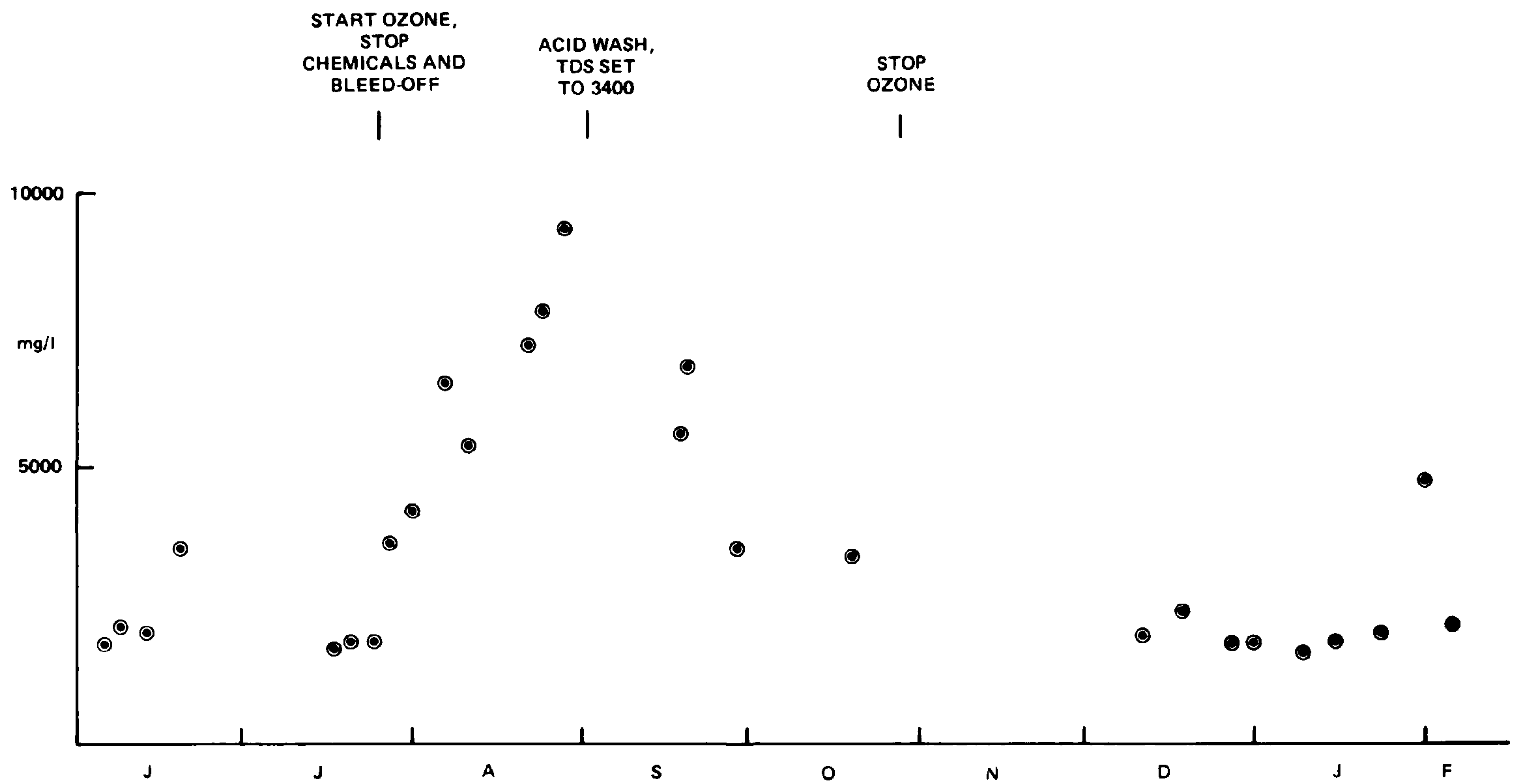

Figure 6. Total dissolved solids (TDS) concentration (mg/l) in the cooling tower water, plotted as a function of time.

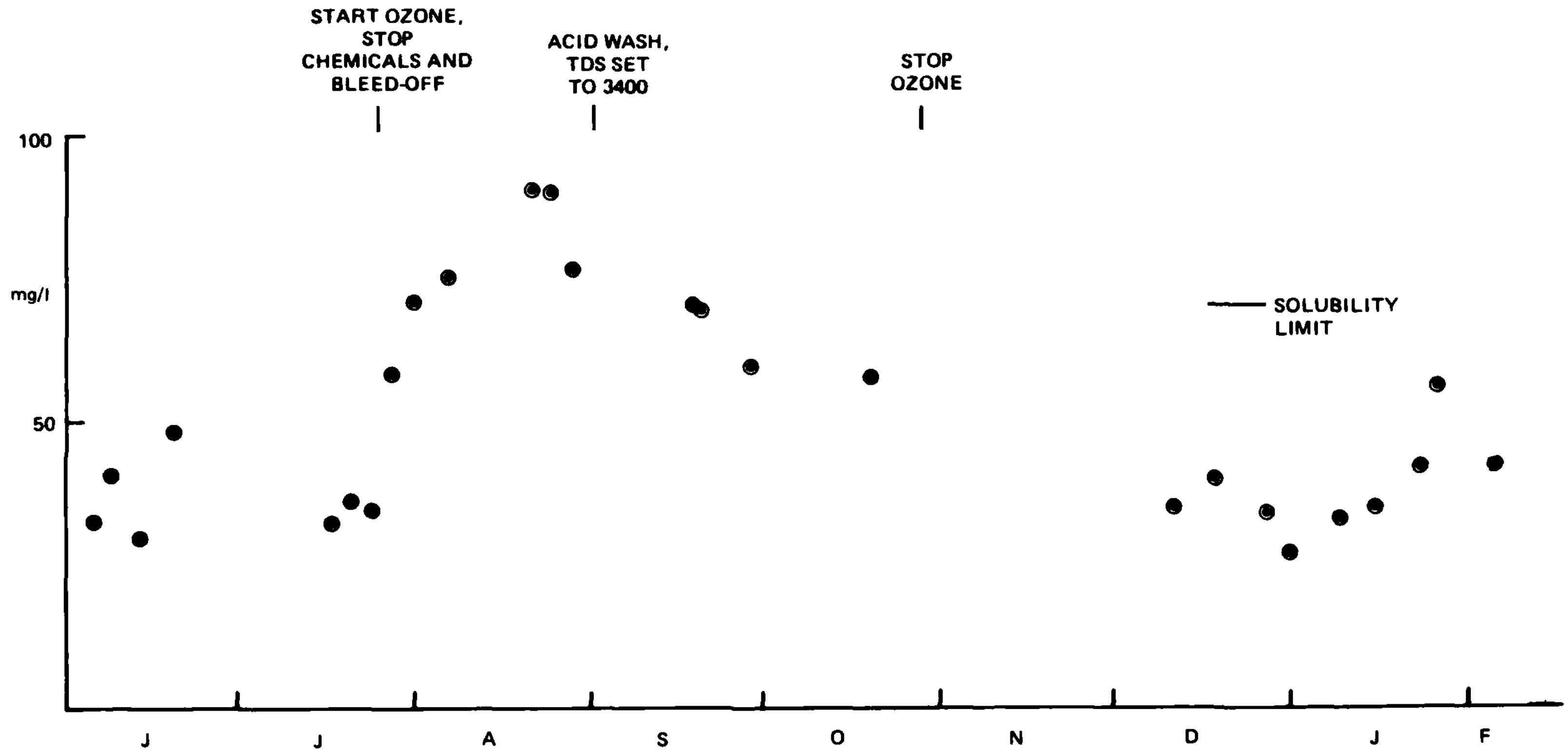

Figure 7. Silicon concentration (mg/l) in the cooling tower water, plotted as a function of time.

DISCUSSION AND RECOMMENDATIONS

The results of the various measurements and analyses are shown in the graphs of figures 6 through 9, in the data listed in table 1, and in the laboratory reports in the appendix.

Table 1. Annual cost savings.

Annual Costs	
Chemicals (Aqua-Serv Engineers, Los Angeles, CA)	
L-720 (corrosion inhibitor)	$3,300.00
A-106 (algaecide)	290.00
HTH (chlorine)	420.00
TOTAL	$4,010.00
Ozone (capital, operating, maintenance)	
Concentrator/generator (10-year life cycle)	$ 350.00
Concentrator/generator (operating)	1,300.00
Circulation pump (operating)	1,500.00
TOTAL	$3,150.00
Annual Savings (material only)	$ 860.00

The silicon concentration data of figure 7 are closely related to the condenser scaling problem described above. At room temperature, the saturation concentration for silicon in water is typically 70 mg/l. Since solubility varies inversely with temperature, precipitation will occur when and where temperatures are high enough to exceed the saturation limit, such as in condenser tubes. The data of figure 7 show that the silicon concentration under bleed-off control (pre- and post-ozone) varies between 30 and 50 mg/l, to provide a comfortable margin for solubility, even at elevated temperatures. However, when the basin water silicon concentration is allowed to reach levels as high as those shown in figure 7, precipitation and, therefore, scaling in condenser tubes is a virtual certainty. This will occur under either chemical or ozone application, since neither will react with silicon. The silicon concentration can be controlled only by introducing make-up water (i.e., bleed-off) where the silicon concentration is typically 11 mg/l (see laboratory sample 9882 in appendix A). It is simply not true that a cooling tower water system will operate satisfactorily without bleed-off, as some ozone proponents have advocated. Note, however, that the bleed-off volume necessary to prevent scaling in the NOSC system is only 126 gallons per day, or less than two percent of the total make-up water consumption. In the case of the NOSC tower, at least, the inability to go to zero bleed-off under ozone is a trivial factor in the cost savings. Because ozone was held responsible for the corrosion problem discussed briefly earlier in this text (see Measurements and Results), the issue should be expanded here. First, because of the critical nature of the computer space conditioned by the chillers, it was entirely proper to terminate the ozone project when it appeared that damage might result to the

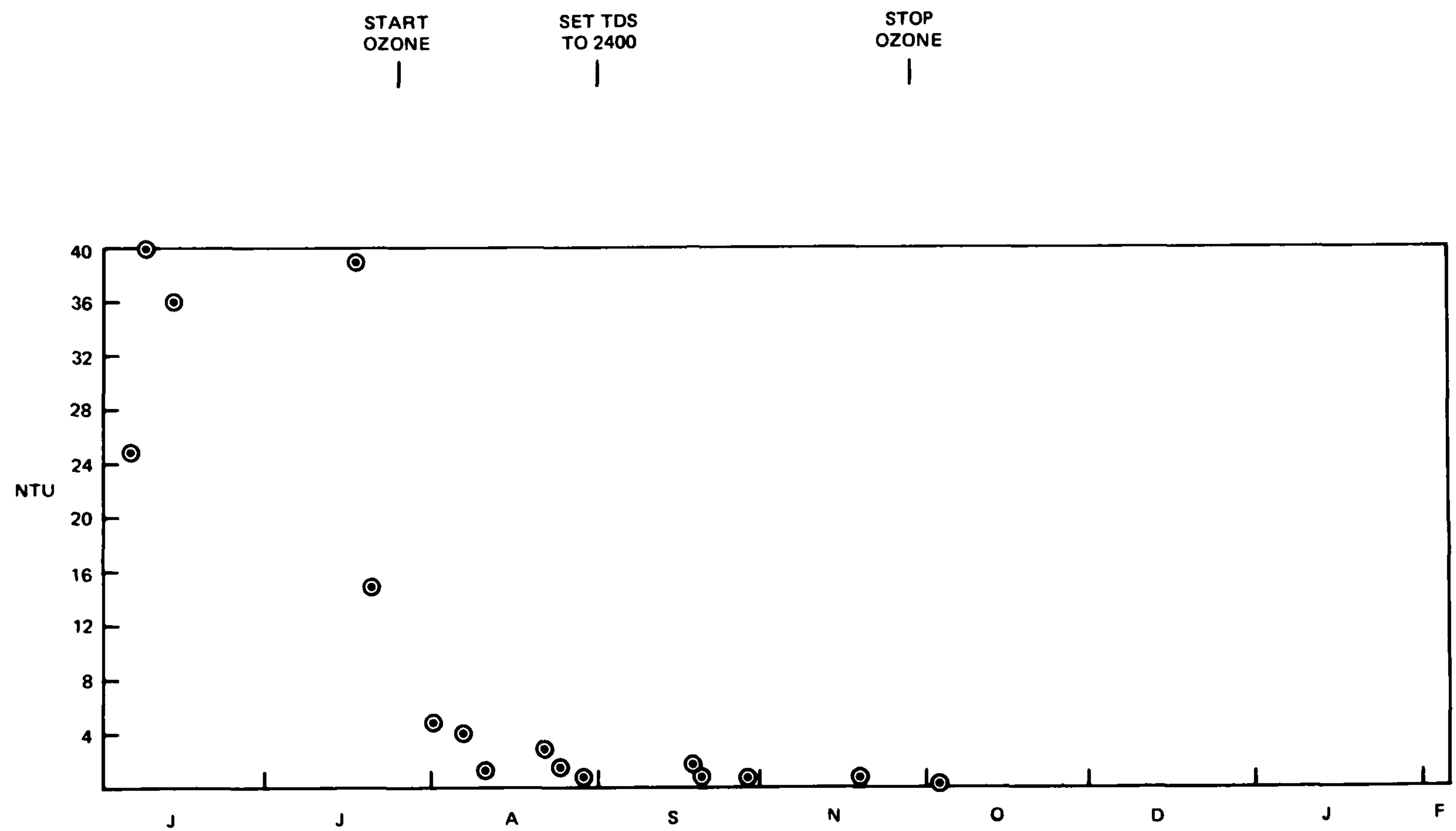

Figure 8. Turbidity of the cooling tower water (NTV), plotted as a function of time.

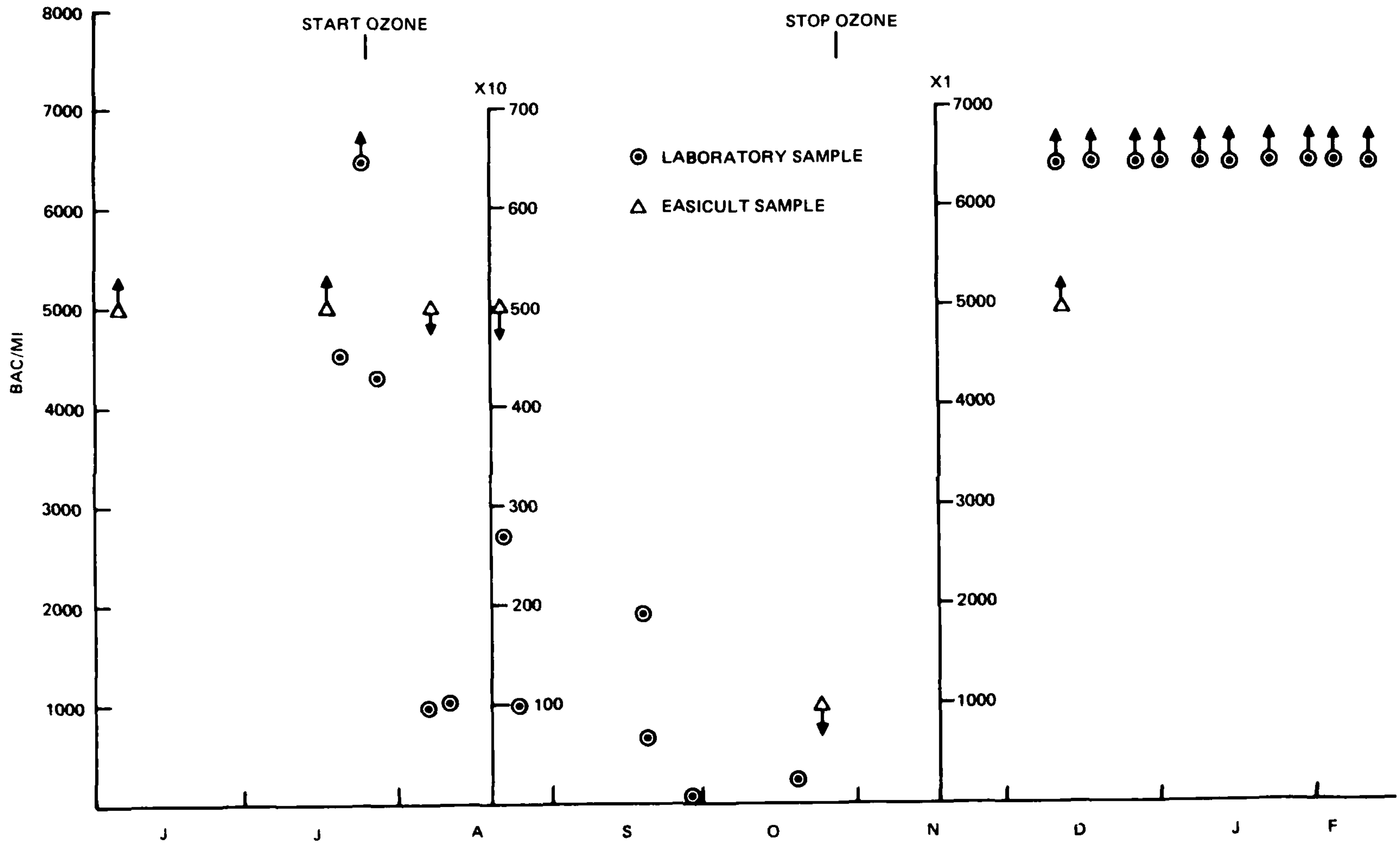

Figure 9. Bacterial plate count (#/ml) in the cooling tower water, plotted as a function of time.

computer system. Future ozone/cooling tower projects at NOSC should be confined to less critical installations until it is abundantly clear that the "experimental" phase is over.

With regard to the air compressors, it is significant that there are two side plates mounted on each compressor, or four in all, and that corrosion occurred in only one plate. None of the other plates was damaged. Furthermore, there is no way to determine how long the corrosive action had been occurring; i.e., it could have been the result of the chemicals working for several years, with no causal relationship to the ozone at all. Reference to the literature (ref. 8) indicates that the ozone concentration maintained in the NOSC tower water, approximately 10μg/l, was at the low end of the range recommended for effective treatment, and where corrosion is not a problem. A final note on the air compressors is that although the compressors are made of iron (they are magnetic), the original plates are made of cast aluminum. Their replacements were made at NOSC, also of (machined) aluminum. The dissimilar metals are, of course, potential sources of corrosive galvanic action.

Among the substantial benefits which were derived from this experiment are annual cost savings, as summarized in table 1, and biological control, as displayed in figures 8 and 9.

The chemical costs listed in the table are for materials only (ref 9), and do not include associated labor charges. The ozone costs are based on a ten-year life cycle, assume a 100 percent (24-hour) duty cycle, and include maintenance. Although the savings are small, only $800 per year, the inclusion of labor charges for chemical handling (to raise those costs) and the use of feed-back (microcomputer) control for the ozone system (to increase operating efficiency) would substantially raise the annual savings. In addition, the other less tangible, but nevertheless important, benefits, such as the elimination of chemically produced environmental pollution, will still be realized.

The remaining two graphs, figures 8 and 9, demonstrate the biocidal effectiveness of zone in the treatment of cooling tower water. The turbidity data, closely realted to algae growth, are also supported by the daily visual examination data which showed rapid clearing of the basin water. No turbidity data are available for the post-ozone period since the Navy laboratory is not equipped for those measurements. However, visual examinations indicate that the algae growth is returning to initial levels. To explain the turbidity unit used in the ARCO reports, the NTU represents "nephelometric turbidity unit," a measure of the amount of 90 degree scattering (ref. 10).

An auxiliary benefit which resulted from the ozone produced high water clarity is the opportunity to clean the tower basin without the need to drain the water. Since the basin bottom is clearly visible, cleaning is easily and quickly accomplished in about 2 hours with a swimming pool hose and vacuum attachment under siphon flow. Previously, cleaning required basin drainage and tower shut-down for at least one day. Over time, the labor savings for tower maintenance could be substantial.

The bacterial data of figure 9 are closely related to those for the algae, in that they are both biological and both show a high degree of sensitivity to ozone. Since laboratory analyses for bacteria count were not

included in the first few ARCO reports, only three samples appear in the pre-ozone baseline data (plotted as circles). The circle datum with the arrow attached signifies that the count exceeds the plot value of 6500 count/ml, the maximum reported by the laboratory. In any event, all three samples easily exceed 4000 count/ml. As the data in the figure show, the count began to fall under ozone treatment, reaching a low of 5 in one September sample. After ozone termination, however, the plate counts returned to their initial high levels, exceeding the Navy laboratory maximum reporting value of 6400 count/ml for all the post-ozone samples. Reference to figure 9 again shows that, in addition to the laboratory data plotted as circles, data plotted in triangle form also appear. These data were recorded by the author using the Easicult (ref. 11) application, and provide a comparison to the laboratory data. Easicult data are calibrated for plate count by visual comparison to a model chart, so that the precision is limited to an order-of-magnitude. As a result, the Easicult (triangle) data in figure 9 have arrows attached to indicate the appropriate value limits. Although the Easicult calibrations are not precise, they are easy to take (full instructions included), require no incubation (24 hours on the shelf at room temperature), and provide quick estimates of gross bacterial levels. Since many bacteria are potentially harmful to humans (e.g., legionella pneumophilla), it is recommended here that Easicult samples be taken on a regular basis from water systems where personnel are subject to exposure. It is significant that the first post-ozone sample produced a cautionary message from the Navy laboratory (ref. 12) when the bacteria count exceeded their alarm level of 600 count/ml (recall that all post-ozone samples exceeded 6400 count/ml). Furthermore, the sample (ref. 12) of 1 February 1984 contained coliform bacillus, perhaps of bird origin. Although the NOSC cooling tower poses little or no health threat to general personnel, there are multiple structure complexes (many in the Navy) where the drift from a cooling tower can enter the intake of a nearby air handling system. In such cases, genuine hazards exist.

Although it is not related to the ozone treatment, a totally unexpected financial benefit to NOSC was realized from the ozone project. NOSC pays $2.00 per thousand gallons for fresh water and, under the assumption that 80 percent of that water requires sewage disposal, NOSC is charged $1.60 per thousand gallons for water discharged to the sewer system (ref. 13). However, as described above, the meters installed on the Building 1 cooling tower show that virtually all the water used by that unit (nearly 10,000 gallons per day) is lost by drift and evaporation and does not use the sewer system. By renegotiating the water contract to reduce the sewer costs appropriately, NOSC could realize a savings of over $6,000 per year, easily enough to make it worth the effort.

To summarize, then, all Navy cooling towers should be examined to establish their eligibility for ozone treatment. Then, using the results achieved from the present experiment, those towers certified as eligible should be placed on an early schedule for conversion to ozone. Concurrently, work should also continue on the development of a microcomputer-based, on-line, feed-back control system to precisely measure and maintain dissolved ozone levels within their appropriate ranges.

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12. P. Mah, U. S. Navy Public Works Center Environmental Laboratory, Private Communication.

13. LCDR D. M. King, Public Works Officer, NOSC Civil Engineering Department, Private Communication.

APPENDIX A

CHEMICAL ANALYSES

ARCO Ventures Company
Division of AtlanticRichfieldCompany

Water Analysis

Technical Center
6905 Sierra Court
Dublin, California 94566
Telephone 415 828 5000

This is No Carbon Required paper

To
Dr. J.P. Hurley
Code 534
Naval Ocean Systems Center
271 Catalina
San Diego, CA. 92152

Report date: 6/21/83
Date received: 6/6/83
Date sampled:
Sampler:

Laboratory number	Sample identifying mark
9417	

Laboratory number		9417			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	305			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	550			
Alkalinity, Total (as $CaCO_3$)	mg/l	496			
Calcium, Ca	mg/l	217			
Magnesium, Mg	mg/l	786			
Iron, Fe	mg/l	0.15			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	62.2			
Potassium, K	mg/l				
Copper, Cu	mg/l	< 0.01			
Nitrate, NO_3^-	mg/l	1.7			
Hardness (as $CaCO_3$)	mg/l	850			
Filterable Residue TDS	mg/l	1876			
Non-filterable Residue, SS	mg/l	38			
pH Electrometric		8.8			
Specific Conductance	u mhos				
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	25			
Plate Count	bacteria/ml				
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
~~xxxx~~ Chemical Oxygen Demand, COD	mg/1				
Total Organic Carbon	mg/1	36			
Chromium	mg/1	< 0.01			
Phosphorous	mg/1				
Zinc	mg/1	< 0.008			
Aluminum	mg/1	< 0.15			
Silicon	mg/1	32.9			

ARCO 2302
(12 80)

Laboratory director Ralph A. [illegible]

ARCO Ventures Company
Division of AtlanticRichfieldCompany

Water Analysis

Technical Center
6905 Sierra Court
Dublin, California 94566
Telephone 415 828 5000

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To

DR. J. P. HURLEY
CODE 534
NAVAL OCEAN SYSTEMS CENTER
271 CATALINA
SAN DIEGO, CA 92152

Report date 6/21/83
Date received 6/9/83
Date sampled
Sampler

Laboratory number	Sample identifying mark
9424	

Laboratory number		9424			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	340			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	850			
Alkalinity, Total (as $CaCO_3$)	mg/l	484			
Calcium, Ca	mg/l	257			
Magnesium, Mg	mg/l	94			
Iron, Fe	mg/l	< 0.01			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	258			
Potassium, K	mg/l				
Copper, Cu	mg/l	0.17			
Nitrate, NO_3^-	mg/l	1.4			
Hardness (as $CaCO_3$)	mg/l	920			
Filterable Residue TDS	mg/l	2120			
Non-filterable Residue, SS	mg/l	123			
pH Electrometric		8.8			
Specific Conductance	u mhos				
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	40			
Plate Count	bacteria/ml				
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Chemical Oxygen Demand, COD	mg/l				
Total Organic Carbon	mg/l	44			
Chromium	mg/l	0.07			
Phosphorous	mg/l				
Zinc	mg/l	0.077			
Aluminum	mg/l	< 0.15			
Silicon	mg/l	40.6			

ARCO-2302
(12-80)

Laboratory director Ralph C. [illegible]

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Division of AtlanticRichfieldCompany

Water Analysis

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To

DR. J. P. HURLEY
CODE 534
NAVAL OCEAN SYSTEMS CENTER
271 CATALINA
SAN DIEGO, CA 92152

Report date: 6-21-83
Date received: 6-14-83
Date sampled:
Sampler:

Laboratory number	Sample identifying mark
9452	

Laboratory number		9452			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	290			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	625			
Alkalinity, Total (as $CaCO_3$)	mg/l	482			
Calcium, Ca	mg/l	202			
Magnesium, Mg	mg/l	73.5			
Iron, Fe	mg/l	0.01			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	188			
Potassium, K	mg/l				
Copper, Cu	mg/l	0.08			
Nitrate, NO_3^-	mg/l	2.2			
Hardness (as $CaCO_3$)	mg/l	874			
Filterable Residue TDS	mg/l	2036			
Non-filterable Residue, SS	mg/l	96			
pH Electrometric		8.8			
Specific Conductance	u mhos				
Color Color Units (Chloroplatinate)					
Turbidity	NTU	36			
Plate Count	bacteria/ml				
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
~~xxxx~~ Chemical Oxygen Demand, COD	mg/l				
Total Organic Carbon	mg/l	40			
Chromium	mg/l	0.06			
Phosphorous	mg/l				
Zinc	mg/l	0.05			
Aluminum	mg/l	< 0.15			
Silicon	mg/l	29.8			

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(12-80)

Laboratory director Ralph A. Tice

ARCO Ventures Company

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Water Analysis

Technical Center
6805 Sierra Court
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Telephone 415 828 5000

To	
DR. J. P. HURLEY CODE 534 NAVAL OCEAN SYSTEMS CENTER 271 CATALINA SAN DIEGO, CA 92152	Report date 7/20/83 Date received 6/20/83 Date sampled Sampler

Laboratory number	Sample identifying mark
9462	6-20-83

Laboratory number					
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	632			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	1175			
Alkalinity, Total (as $CaCO_3$)	mg/l	654			
Calcium, Ca	mg/l	254			
Magnesium, Mg	mg/l	128			
Iron, Fe	mg/l	0.07			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	321			
Potassium, K	mg/l				
Copper, Cu	mg/l	0.02			
Nitrate, NO_3^-	mg/l	1.3			
Hardness (as $CaCO_3$)	mg/l	1425			
Filterable Residue TDS	mg/l	3580			
Non-filterable Residue, SS	mg/l	25			
pH Electrometric		8.7			
Specific Conductance	u mhos				
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	7.5			
Plate Count	bacteria/ml				
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Chemical Oxygen Demand, COD	mg/1				
Total Organic Carbon	mg/1	41			
Chromium	mg/1	0.06			
Phosphorous	mg/1				
Zinc	mg/1	0.05			
Aluminum	mg/1	<0.15			
Silicon	mg/1	48.2			

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(12-80)

Laboratory director Ralph A. [illegible]

ARCO Ventures Company
Division of AtlanticRichfieldCompany

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6905 Sierra Court
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Telephone 415 828 5000

Water Analysis

[redacted]

To

DR. J. P. HURLEY
CODE 534
NAVAL OCEAN SYSTEMS CENTER
271 CATALINA
SAN DIEGO, CA 92152

Report date: 7/20/83
Date received: 7/18/83
Date sampled:
Sampler:

Laboratory number	Sample identifying mark
9552	7-18-83

Laboratory number		9552			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	300			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	625			
Alkalinity, Total (as $CaCO_3$)	mg/l	437			
Calcium, Ca	mg/l	177			
Magnesium, Mg	mg/l	58			
Iron, Fe	mg/l	0.68			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	193			
Potassium, K	mg/l				
Copper, Cu	mg/l	0.01			
Nitrate, NO_3^-	mg/l	1.9			
Hardness (as $CaCO_3$)	mg/l	852			
Filterable Residue TDS	mg/l	1755			
Non-filterable Residue, SS	mg/l	41			
pH Electrometric		8.8			
Specific Conductance	u mhos				
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	39			
Plate Count	bacteria/ml				
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
~~xxxx~~ Chemical Oxygen Demand, COD	mg/1				
Total Organic Carbon	mg/1	34			
Chromium	mg/1	0.10			
Phosphorous	mg/1				
Zinc	mg/1	0.07			
Aluminum	mg/1	0.99			
Silicon	mg/1	32.2			

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Laboratory director [illegible]

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To	
DR. J. P. HURLEY CODE 534 271 CATALINA SAN DIEGO, CA 92152	Report date: 07/25/83 Date received: 07/21/83 Date sampled: Sampler:

Laboratory number	Sample identifying mark
9578	07/21/83

Laboratory number		9578			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	310			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	625			
Alkalinity, Total (as $CaCO_3$)	mg/l	416			
Calcium, Ca	mg/l	205			
Magnesium, Mg	mg/l	71.6			
Iron, Fe	mg/l	0.43			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	232			
Potassium, K	mg/l				
Copper, Cu	mg/l	0.10			
Nitrate, NO_3^-	mg/l	1.6			
Hardness (as $CaCO_3$)	mg/l	828			
Filterable Residue TDS	mg/l	1885			
Non-filterable Residue, SS	mg/l	24			
pH Electrometric					
Specific Conductance	u mhos	1700			
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	15			
Plate Count	bacteria/ml	4510			
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Chemical Oxygen Demand, COD	mg/1				
Total Organic Carbon	mg/1	31			
Chromium	mg/1	0.04			
Phosphorous	mg/1				
Zinc	mg/1	0.05			
Aluminum	mg/1	<0.15			
Silicon	mg/1	363			

Laboratory director Ralph C [illegible]

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Water Analysis

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To

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CODE 534
NAVAL OCEAN SYSTEMS CENTER
271 CATALINA
SAN DIEGO, CA 92152

Report date 08/01/83
Date received
Date sampled
Sampler

Laboratory number	Sample identifying mark
9666	07/25/83
9668	07/28/83

Laboratory number		9666	9668		
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	327	645		
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	725	1375		
Alkalinity, Total (as $CaCO_3$)	mg/l	438	596		
Calcium, Ca	mg/l	210	364		
Magnesium, Mg	mg/l	71.8	143		
Iron, Fe	mg/l	0.03	0.21		
Manganese, Mn	mg/l				
Sodium, Na	mg/l	238	474		
Potassium, K	mg/l				
Copper, Cu	mg/l	0.06	0.04		
Nitrate, NO_3^-	mg/l	1.0	3.0		
Hardness (as $CaCO_3$)	mg/l	440	1520		
Filterable Residue TDS	mg/l	1890	3652		
Non-filterable Residue, SS	mg/l	10	17		
pH Electrometric		8.7	8.7		
Specific Conductance	u mhos	2100	3900		
Color Color Units (Chloroplatinate)					
Turbidity	NTU				
Plate Count	bacteria/ml	> 6500	4290		
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Other					
TOTAL ORGANIC CARBON	mg/1	49	24		
CHROMIUM	mg/1	0.08	0.12		
ZINC		0.03	0.05		
ALUMINUM		< 0.15	0.25		
SILICON		34.8	58.2		

Laboratory director Ralph A. Duce

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To	
DR. J. P. HURLEY CODE 534 NAVAL OCEAN SYSTEMS CENTER 271 CATALINA SAN DIEGO, CA 92152	Report date: 8-10-83 Date received: 8-1-83 Date sampled: Sampler:

Laboratory number	Sample identifying mark
9716	8-1-83

Laboratory number		9716			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	1000			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	1950			
Alkalinity, Total (as $CaCO_3$)	mg/l	458			
Calcium, Ca	mg/l	386			
Magnesium, Mg	mg/l	200			
Iron, Fe	mg/l	< 0.01			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	309			
Potassium, K	mg/l				
Copper, Cu	mg/l	< 0.01			
Nitrate, NO_3^-	mg/l	3.57			
Hardness (as $CaCO_3$)	mg/l	1868			
Filterable Residue TDS	mg/l	4250			
Non-filterable Residue, SS	mg/l	31			
pH Electrometric		8.7			
Specific Conductance	u mhos	4000			
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	4.7			
Plate Count	bacteria/ml	Lost			
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Other					
Total Organic Carbon	mg/1	35			
Chromium	mg/1	0.07			
Phosphorous	mg/1	0.13			
Zinc	mg/1	0.04			
Aluminum	mg/1	< 0.15			
Silicon	mg/1	70.9			

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(12-80)

Laboratory director [illegible]

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Water Analysis

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To

DR. J. P. HURLEY
CODE 534
NAVAL OCEAN SYSTEMS CENTER
271 CATALINA
SAN DIEGO, CA 92152

Report date 08/12/83
Date received 08/07/83
Date sampled
Sampler

Laboratory number	Sample identifying mark
9727	8-7-83

Laboratory number		9727			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	1440			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	2500			
Alkalinity, Total (as $CaCO_3$)	mg/l	432			
Calcium, Ca	mg/l	447			
Magnesium, Mg	mg/l	278			
Iron, Fe	mg/l	<0.01			
Manganese, Mn	mg/l				
Sodium, Na	mg/l	1020			
Potassium, K	mg/l				
Copper, Cu	mg/l	<0.01			
Nitrate, NO_3^-	mg/l	5.9			
Hardness (as $CaCO_3$)	mg/l	2360			
Filterable Residue TDS	mg/l	6524			
Non-filterable Residue, SS	mg/l	30			
pH Electrometric		8.8			
Specific Conductance	u mhos	5100			
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	4.0			
Plate Count	bacteria/ml	980			
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Other					
Total organic carbon	mg/1	62			
Chromium, Cr	mg/1	0.09			
Zinc, Zn	mg/1	0.04			
Aluminum, Al	mg/1	<0.15			
Silicon, Si	mg/1	75.4			

Laboratory director [signature]

A R CO -2302

ARCO Ventures Company

Division of AtlanticRichfieldCompany

Water Analysis

Technical Center
6905 Sierra Court
Dublin, California 94566
Telephone 415 828 5300

To	
DR. J. P. HURLEY CODE 534 NAVAL OCEAN SYSTEMS CENTER 27: CATALINA SAI DILGO, CA 92152	Report date: 09/09/83 Date received: Date sampled: Sampler:

Laboratory number	Sample identifying mark
9738	08/11/83
9801	08/22/83
9818	08/25/83
9823	08/29/83

Laboratory number		9738	9801	9818	9823
Bicarbonate, HCO_3^- (as CaCO3)	mg/l				
Carbonate, $CO_3^=$ (as CaCO3)	mg/l				
Hydroxyl, OH^- (as CaCO3)	mg/l				
Chloride, Cl^-	mg/l	1100	1700	1830	2270
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	2175	2250	2625	3135
Alkalinity, Total (as CaCO3)	mg/l	408	550	520	530
Calcium, Ca	mg/l		502	542	573
Magnesium, Mg	mg/l		365	401	405
Iron, Fe	mg/l		0.01	<0.01	<0.01
Manganese, Mn	mg/l		<0.005	<0.005	<0.005
Sodium, Na	mg/l		1405	3300	3760
Potassium, K	mg/l		106	121	132
Copper, Cu	mg/l		<0.01	<0.01	<0.01
Nitrate, NO_3^-	mg/l	6.5	6.4	6.3	10.
Hardness (as CaCO3)	mg/l	1900	2440	2710	3100
Filterable Residue TDS	mg/l	5420	7210	7844	9376
Non-filterable Residue, S	mg/l	19	33	12	30
pH Electrometric		8.8	8.7	8.7	8.8
Specific Conductance	u mhos	4500	6400	7600	7500
Color Color Units (Chloroplatinate)					
Turbidity	NTU	1.3	3.0	1.5	0.7
Plate Count	bacteria/ml	1040	270	10	2600
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Other					
Total organic carbon	mg/l	54	69.6	159	77
Chromium, Cr	mg/l		0.16	0.17	0.17
Zinc, Zn	mg/l		0.07	0.09	0.07
Aluminum, Al	mg/l		<0.15	<0.15	<0.15
Silicon, Si	mg/l		90.4	90.0	76.4

Laboratory director: Ralph A. [illegible]

ARCO-2302
(12-)

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To

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NAVAL OCEAN SYSTEMS CENTER
271 CATALINA
SAN DIEGO, CA 92152

Report date: 10/04/83
Date received:
Date sampled:
Sampler:

Laboratory number	Sample identifying mark
9874	9/19/83
9880	9/20/83
9882	9/22/83 MAKE UP WATER
9901	9/29/83

Laboratory number		9874	9880	9882	9901
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	1275	1760	78	830
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	1625	2300	85	1325
Alkalinity, Total (as $CaCO_3$)	mg/l	365	370	96	234
Calcium, Ca	mg/l	383	458	47.6	250
Magnesium, Mg	mg/l	221	260	14.3	139
Iron, Fe	mg/l	< 0.01	< 0.01	< 0.01	< 0.01
Manganese, Mn	mg/l				
Sodium, Na	mg/l	811	1040	49.3	528
Potassium, K	mg/l				
Copper, Cu	mg/l	< 0.01	< 0.01	< 0.01	< 0.01
Nitrate, NO_3^-	mg/l	6.3	7.02	< 0.1	3.7
Hardness (as $CaCO_3$)	mg/l	2080	2710	320	1490
Filterable Residue TDS	mg/l	5650	6870	368	3560
Non-filterable Residue, SS	mg/l	24	3.5	0.5	0.5
pH Electrometric		8.7	8.8	7.0	8.9
Specific Conductance	u mhos	4500	6400	540	3500
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	1.7	0.7	0.31	0.43
Plate Count	bacteria/ml	190	65		5
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Chemical Oxygen Demand, COD	mg/1				
Total Organic Carbon	mg/1	52	54	14.6	29.4
Chromium	mg/1	0.10	0.11	0.02	< 0.01
~~Phosphorous~~	~~mg/1~~	0.08	0.06	0.61	0.03
Zinc	mg/1	< 0.15	< 0.15	< 0.15	< 0.15
Aluminum	mg/1	70.5	69.9	10.55	59.3
Silicon	mg/1				

A R CO -2302
(12-80)

Laboratory director: Ralph A. [signature]

ARCO Ventures Company
Division of AtlanticRichfieldCompany

Water Analysis

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To	
DR. J. P. HURLEY CODE 534 NAVAL OCEAN SYSTEMS CENTER 271 CATALINA SAN DIEGO, CA 92152	Report date: 11/02/83 Date received: 10/20/83 Date sampled: Sampler:

Laboratory number	Sample identifying mark
9949	10/20/83

Laboratory number		9949			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	640			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	1125			
Alkalinity, Total (as $CaCO_3$)	mg/l	400			
Calcium, Ca	mg/l	238			
Magnesium, Mg	mg/l	131			
Iron, Fe	mg/l	0.01			
Manganese, Mn	mg/l	(0.01			
Sodium, Na	mg/l	421			
Potassium, K	mg/l	30.7			
Copper, Cu	mg/l	0.01			
Nitrate, NO_3^-	mg/l	5.2			
Hardness (as $CaCO_3$)	mg/l	1650			
Filterable Residue TDS	mg/l	3400			
Non-filterable Residue, SS	mg/l	2.5			
pH Electrometric		8.6			
Specific Conductance	u mhos	4000			
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	0.43			
Plate Count	bacteria/ml	26			
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Other					
Total organic carbon	mg/l	21.0			
Chromium, Cr	mg/l	0.10			
Zinc, Zn	mg/l	0.09			
Aluminum, Al	mg/l	(0.15			
Silicon, Si	mg/l	57.6			

A R.CO -2302
(12-80)

Laboratory director Ralph A. Price

ARCO Ventures Company
Division of Atlantic RichfieldCompany

Technical Center
6905 Sierra Court
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Water Analysis

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To

DR. J. P. HURLEY
CODE 534
NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CA 92152

Report date: 11/23/83
Date received: 11/03/83
Date sampled:
Sampler:

Laboratory number	Sample identifying mark
10004	11/03/83

Laboratory number		10004			
Bicarbonate, HCO_3^- (as $CaCO_3$)	mg/l				
Carbonate, $CO_3^=$ (as $CaCO_3$)	mg/l				
Hydroxyl, OH^- (as $CaCO_3$)	mg/l				
Chloride, Cl^-	mg/l	349			
Fluoride, F^-	mg/l				
Sulfate, $SO_4^=$	mg/l	1000			
Alkalinity, Total (as $CaCO_3$)	mg/l	296			
Calcium, Ca	mg/l	177			
Magnesium, Mg	mg/l	68.2			
Iron, Fe	mg/l	<0.01			
Manganese, Mn	mg/l	<0.005			
Sodium, Na	mg/l	147.3			
Potassium, K	mg/l	9.83			
Copper, Cu	mg/l	<0.01			
Nitrate, NO_3^-	mg/l	1.19			
Hardness (as $CaCO_3$)	mg/l	1110			
Filterable Residue TDS	mg/l	1950			
Non-filterable Residue, SS	mg/l	5.0			
pH Electrometric		8.5			
Specific Conductance	u mhos	2000			
Color, Color Units (Chloroplatinate)					
Turbidity	NTU	0.25			
Plate Count	bacteria/ml	380			
Total Coliform	MPN/100 ml				
Fecal Coliform	MPN/100 ml				
Other					
Total organic carbon	mg/l	11.8			
Chromium, Cr	mg/l	0.07			
Zinc, Zn	mg/l	0.35			
Aluminum, Al	mg/l	<0.15			
Silicon, Si	mg/l	28.5			

Laboratory director: Ralph A. [illegible]

A R CO.-2302
(12-80)

From: Navy Public Works Center
Environmental Laboratory, Code 614
1220 Pacific Highway
San Diego, CA 92132

Mailing Address:
Navy PWC, Code 614, Box 113
Naval Station, San Diego, CA 92136

TO: NOSC, Attn: Dr. J. P. Hurley, San Diego, CA 92152

DATE

REPORT OF ANALYSIS OF:
Cooling Tower Bldg 1

DATE SAMPLE COLLECTED	DATE ANALYSED	ANALYST
		Staff

RESULTS EXPRESSED AS:

SOURCE OF SAMPLES

A Bldg 1 — Cooling Tower	D Bldg 1 — Cooling Tower
B Bldg 1 — Cooling Tower	E Bldg 1 — Cooling Tower
C Bldg 1 — Cooling Tower	F Bldg 1 — Cooling Tower

	A	B	C	D	E	F
Date sample collected	12/12/83	12/19/83	12/28/83	1/31/84	1/10/84	1/16/84
	31214-1	31220-1	31223-1	40102-1	40105-1	40111-1
Ph	8.95	9.00	8.95	8.93	8.95	9.00
Conductivity	2500	3000	2250	2300	2100	2300
T Dissolved Solids	2000	2400	1800	1840	1680	1840
T Hardness	958	1012	785	769	672	727
Chloride Cl^-	320	392	288	292	276	264
Fe	0.10	0.1	0.1	0.13	0.13	0.10
Cu	0.37	0.10	0.54	0.58	0.42	0.60
Cr	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Plate Count	>6,400	>6,400	>6,400	>6,400	>6,400	>6,400
Silica as SiO_2	75.0	85.0	72.5	57.5	70	75

31214-1
31220-1
31223-1
40102-1
40105-1
40111-1

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REPORT OF ANALYSIS OF:
Cooling Tower Bldg 1

DATE SAMPLE COLLECTED	DATE ANALYSED	ANALYST
		Staff

RESULTS EXPRESSED AS:

SOURCE OF SAMPLES

A Bldg 1 — Cooling Tower	D Bldg 1 — Cooling Tower
B Bldg 1 — Cooling Tower	E
C Bldg 1 — Cooling Tower	F

	A	B	C	D	E	F
Date sample collected	1/24/84	2/1/84	2/7/84	2/13/84		
	40120-1	40204-1	40207-1	--		
Ph	9.00	9.08	9.10	--		
Conductivity	2500	6000	2700	--		
T Dissolved Solids	2000	4800	2160	--		
T Hardness	308	1640	798	--		
Chloride Cl^-	764	736	699	--		
Fe	0.25	0.23	0.32	--		
Cu	0.58	0.45	0.39	--		
Cr	1.62	2.25	0.06	--		
Plate Count	>6,400	>6,400	>6,400	>6,400		
Silica as SiO_2	90	120	90	--		

40120-1
40202-1
40207-1

END
DATE
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